RESISTANCE OF COARSE SEDIMENTS OF THE HUNGARIAN DANUBE SECTION AGAINST CLIMATIC AND ENVIRONMENTAL EFFECTS

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Received 28 May 1987

Abstract

Complex studies have been carried out at the Department on the material of gravel fields with different origin by detailed technical-geological evaluation in various parts of the country with the financial support of the Central Geological Office. The demand for the exploration, exploitation and utilization of the gravel field in the Hungarian Danube section and its immediate neighbourhood is the main point (with special reference to the choice of gravel supplying regions for individual areas). The durability of stone materials used for constructions is determined to a great extent by the material quality, characteristics and unfavourable mineral components of the rock. The durability characteristics of the pebbly rocks have to be known before their use in order to ensure the normal functioning of constructions for a desired period of time. This is the objective of the present paper.

Introduction

By durability of rocks we mean their long lasting resistance against atmospheric effects either at their location or in the course of their use.

When we calculate the durability of rocks, we do not assess characteristics of mechanical stability, but the resistance against weathering, i.e. against the combined effect of chemical, physical and organic factors.

There are no rocks resistant against weathering in the geological time scale, therefore in constructions all these effects should be considered within given time limits.

The preliminary determination of durability under laboratory conditions is a complex task. We can model the complex stress taking place in nature by different studies. Durability should be judged on the basis of utilization, as the weathering of an erroneously chosen material causes the destruction of the entire construction. The basic principle of the test standard (MSZ 18289/1) in this respect is that a rock is durable (weather-proof) if the value of the most important property of the rock characteristic changed in the life time of the construction only to an extent that this changed value still corresponds to the necessary limiting value of the property.

The study and evaluation of rocks should be carried out with an accuracy sufficient to the preliminary characterization of the behaviour of the stone material.

For the estimation of the resistance against weathering and environmental effects the combination of mineralogical-geological and other laboratory experiments can be used.

Objective

Coarse elastic rocks consist mainly of scraps of friable rocks. Rock materials of natural occurrences change their properties as a result of mechanical, chemical or physical stress. These changes, and further wearing-away processes occurring due to other environmental effects change the rock in a certain time to an extent that the rock becomes sensitive to the individual effects. We shall make an attempt to determine if the weathering process exceeds a certain extent or not, and what the damage done to the rock to be utilized was.

Methods of studies

Mineralogical-geological analysis

All properties of the rock observable by the naked eye, by reading glass or microscope and characteristic to the durability of the rock during its utilization, should be indicated.

a. *Informative study by macroscopic geological analysis*

These investigations are carried out by the naked eye or reading glass. Simple identification methods and aids such as dilute hydrochloric acid, scratch needle, etc. can also be applied. In the course of study the colour of the rock, its morphology (e.g. orientation, layering, slatiness, etc.), the degree of its wearing-away, the estimated frequency and dimension of visible minerals should be determined.

b. *Analytical geological studies*

The accurate geological classification is determined by microscopic studies. The presence of interstices, their dimensions, the degree of wearing-away should also be indicated.

On the basis of geological analysis (as described in paragraphs a. and b.) the participation of different rock types has been determined in mass percentage. The main rock components in the coarse, clastic sediment (usually the assembly of particle sizes larger than 4 mm of the riverbed material, material of various terrace bodies) have been determined by using the results of different authors for the locations shown in Figs 1 and 2.

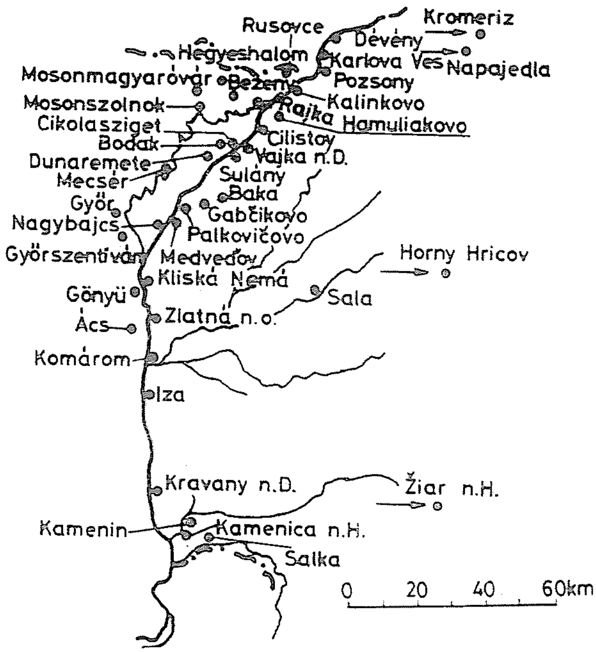


Fig. 1. Sediment sampling places in the Kisalföld and central chain regions of the Danube

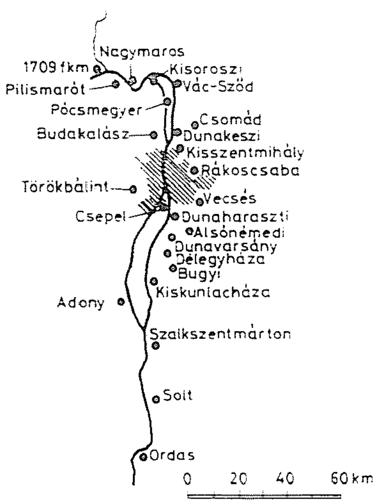


Fig. 2. Sediment sampling places in the Nagyalföld region of the Danube

Geological studies have also been carried out on the deposits of the tributaries of the Danube, the rivers Morva, Vág, Garam and Ipoly. It could be established that corresponding to the geological structure of the area, the quartz and quartzite rocks show a large scatter in the sediment of the tributaries; in the case of the river Morva it is 48—58 wt.%, for the Vág it is 7 and 52 wt.% in the two sampling locations, for the Garam, also for two locations: 12 and 58 wt.%, whereas it is 61 wt.% for the Ipoly.

In the Kisalföld and the region of the central chain of mountains in the Danube region the above rocks are present in 47—89 wt.%. These rocks are hard and resistant to wearing-away (Table 1).

The ratio of *quartz, quartzite* is 60—92 wt.% *Magmatic rocks* are represented in the Kisalföld region by granite and quartz porphyry, whereas in the Nagyalföld region different andezite variants arepresent. In the sediment of the left-tributaries of the Danube in the Kisalföld region the magmatic part of rocks is high, in that of the Vág it is 37 wt.% the Garam 71 wt.% and the Ipoly 32 wt.%.

Volcanic tuff was found in the sediment of the above tributaries and in the pleistocene sediment of the Nagyalföld (in the Kisalföld region andezite and dacite tuffs, in the Nagyalföld region andezite tuff variants).

Sedimentary rocks (compact sea limestone, coarse limestone, sandstone of variable particle sizes, marl, arcose, etc.) are present in the sediment of the Kisalföld region at Rajka, Bezenye and Mosonmagyaróvár in 15—28 wt.%, in the drift beds of the Vág in 50 wt.%, in the sediment south of Budapest in 13 wt.% maximum.

The compact limestone is not layered, the size of calcite minerals is 10—30 μm. The fissures in the rock (thickness: 20—300 μm) are filled with calcite. A fine capillary system is also observable in the rocks, in which case the 10—30 μm fissures are filled with limonite.

The different particle size sandstones (fine and coarse) mostly with a siliceous binding material are recrystallized, quartitized. The size of the minerals is between 50—200 μm.

Strongly weathered rocks are marl, lime marl and arcose. In marl rocks, fissures of 20—600 μm filled with calcite and porous rock rubble are quite frequent.

Stone material, such as phyllite, quartz phyllite, chlorite, slate, mica schist, graphitic quartzite slate, amphybolite, gneiss etc. belonging to *metamorphic rock groups* are also faded, weathered materials. They have limonitic, chloritic colouration. In the profiles of pebble mines and drillings in the Kisalföld region (Bezenye, Hegyeshalom, Mecsér, etc.) they participate in a 20—25 wt.%, whereas in pebble occurrences in the Nagyalföld region in a 10 wt.%. However, they are present in a 2—4 wt.% in every rock sampling location.

The stone shown originates from the ablation region of the Hungarian-Alpian-Carpathian central chain.

A more accurate knowledge about the structure of rocks and the character of minerals can be obtained through elaborating finer details by analytical geological investigations.

Fig. 3. Gneiss. Crossed Nikols. Magnification: 25 × Fine-grained, slightly oriented texture. Quartz, ortoclase, plagioclase, muscovite, biotite, hematite, limonite content. Dimensions: Quartz minerals: 150—2000 μm. ortoclase: 300—1000 μm, mica: 50—300 μm

Fig. 4. Weathered amphybolite. Crossed Nikols. Magn.: 25 × Amphyboles are corroded, fissured minerals. Quartz particles of 100—800 μm are contained. The sericite crystals are formed by the decomposition of feldspars. Minor amounts of epidote. zoizite and granate are also present

Figures 3, 4 and 5 show the rock composition of the pebble sediment in the Kisalföld region (gneisz, amphybolite, limestone), whereas Figs 6, 7 and 8 illustrate that of the Nagyalföld region (granite, andezite, andezite tuff).

Thus it is seen that in the coarse blanket and sediment of the Danube and its tributaries, besides quartz and quartzite highly resistant against drift erosion, variable amounts of magmatic rocks (eruptive, metamorphic and sedimentary) can also be identified.

Fig. 5. Sandy limestone. Crossed Nikols. Magnification: 25 × Patite calcite particles, magmatic quartz, biotite, muscovite, limonite, hematite are also present. Its quartz minerals are 40—220 μm, slightly rounded particles. Limonite and hematite are spot-type occurrences

Fig. 6. Fine-grained granite. Crossed Nikols. Magn.: 68 × Holocrystallic texture. Quartz, potassium feldspar, biotite, plagioclase, muscovite are present. Its mica minerals are fully chloritized. Its acid feldspar minerals and microclinic minerals are weathered

Fig. 7. Biotite-amphibole andezite. Crossed Nikols. Magn.: 27.5 × Essential minerals: plagioclase, basaltic amphibole, biotite. Porphyric minerals are healthy, sericited, chloritized. In the embedding material magnetite, quartz, chlorite are present. The amphibole minerals have particle sizes of 1000—2000 μm

Fig. 8. Andezite tuff. Crossed Nikols. Magnification: 25 × a rock with blister holes. Particle size: 400—2000 μm. In the embedding material microlites of 100—150 μm are observable. The rock has a caked character. It contains also significant amounts of rock glass, martite and apatite crystals

Table 1

Rock composition of Danube sediments (wt.%)

Sampling locations / Rock components	Quartz-quartzite	Amorphous silicates	Acid magmatic rocks	Basic magm. rocks	Volcanic tuff	Limestone, marl	Sandstone cong.	Quartzite slate	Metamorph. rocks
Kisalföld Danube region									
Dévény, Q	73	×	1	—	—	21	—	—	4
Kromeriz (Morva), Q	58	—	3	—	—	—	34	—	5
Napajedlá (Morva), Q	48	—	3	—	—	—	45	—	4
Karlova Ves, Q	79	×	3	—	—	14	1	—	2
Pozsony, Q	75	1	2	×	—	14	1	—	5
Ruszovce, Q	76	1	2	—	—	17	1	—	3
Kalinkovo, Q	80	2	1	—	—	12	1	—	4
Hamuliakovo, Q	71	1	6	—	—	16	2	—	4
Cilistov, Q	76	2	—	—	—	13	2	—	7
Rajka, Qp_4	68	1	6	—	—	11	10	—	4
Bezenye, Qp_4	63	1	1	—	—	17	11	5	2
Hegyeshalom, Qp-f	54	6	4	—	—	10	6	6	14
Mosonmagyaróvár, Qp_4	60	10	10	—	—	12	3	5	—
Mosonszolnok, Qp_4	89	3	—	—	—	1	1	5	1
Vajka n.D., Q	76	1	3	×	—	14	1	—	4
Sulany, Q	80	1	1	×	—	11	1	—	5
Cikloasziget, Qp_4	71	9	2	—	—	5	3	6	4
Bodak, Qp_4	75	3	2	—	—	10	4	—	6
Baka, Q	80	4	3	—	—	7	2	—	4
Dunaremete, Qp_4	83	2	8	—	—	2	3	—	2
Gabcsikovo, Q	80	1	3	—	—	13	1	—	2
Palčikovo, Q	80	2	1	—	—	12	2	—	3
Mecsér, Qp_4	47	10	10	—	—	6	3	18	6
Medvedov, Q	80	2	1	—	—	12	2	—	3
Nagybajcs, Qp_4	82	1	5	—	—	5	3	—	4
Győr, Qp_2	76	3	1	—	—	5	2	9	4
Győrszentiván, Qp_4	57	1	4	—	—	9	4	17	8
Klizska Nema, Q	85	2	2	—	—	4	4	—	3
Gönyű, k	87	2	3	—	—	6	—	—	2
Zlatna N.O., Q	84	2	1	—	—	2	9	—	2
Horny Hricov (Vág), Q	7	×	35	2	—	23	27	—	5
Sala (Vág), Q	52	2	20	1	—	5	19	—	1
Ács, k	52	18	—	—	—	4	2	14	10
Komárom, k	57	8	2	—	—	3	6	15	9
Central chain Danube section									
Iža, Q	88	2	1	—	—	—	5	—	3
Kravăň n. D., Q	86	1	2	—	—	2	5	—	4
Žiar n. H., (Garam), Q	12	—	25	46	5	—	2	—	10
Kamenin (Garam), Q	58	1	17	18	2	—	1	—	3
Kamenica n. H., Q	85	1	1	6	—	2	3	—	2
Sálka (Ipoly), Q	61	1	—	32	5	—	—	—	×
1709 km, k	78	6	3	—	—	3	3	6	1
Pilismarót, Qh-Qp	79	6	3	—	1	2	—	8	1
Nagyalföld Danube region									
Pócsmegyer, Qp_4	64	4	2	13	—	2	4	7	4
Budakalász, Qp_4	65	5	5	10	4	1	1	5	4
Kisszentmihály, Qp_3	86	3	2	—	—	—	—	9	—
Káposztásmegyer, Qp_4	78	6	4	6	1	×	×	4	×
Cinkota, Pl_3	88	2	—	—	—	1	1	7	×

Table 1 (continued)

Sampling locations / Rock components	Quartz-quartzite	Amorphous silicates	Acid magmatic rocks	Basic magm. rocks	Volcanic tuff	Limestone, marl	Sandstone cong.	Quartzite slate	Metamorph. rocks
Bp. Árpád Bridge, k	80	3	×	2	1	2	—	9	2
Rákoscsaba, Pl_3	87	1	×	2	—	—	5	4	—
Rákoskeresztúr, Pl_3	84	4	—	—	—	—	—	12	—
Pestlőrinc, Pl_3	87	5	—	—	—	—	—	8	—
Vecsés, Pl_3	92	2	—	—	—	×	—	5	—
Csepel, Qp_4	76	3	1	4	3	2	1	8	2
Dunaharaszti, Qp_4	71	2	3	2	2	3	3	11	3
Alsónémedi, Qp_4	74	4	2	3	3	5	1	6	2
Ócsa, 1. Qp-f	70	4	1	4	4	1	2	13	×
Ócsa, 2. Qp-f	78	4	×	5	2	1	×	9	×
Dunavarsány, Qp-f	80	2	×	3	1	2	—	10	1
Délegyháza 1. Qp-f	73	4	×	—	3	2	2	14	1
Délegyháza 2. Qp-f	77	2	×	6	1	2	4	6	1
Bugyi, Qp-f	76	4	2	2	—	2	4	8	2
Kiskunlacháza, Qp-f	60	4	1	7	3	11	×	13	×
Adony, k	74	4	—	4	1	2	1	11	3
Szalkszentmárton, Qp_4	69	4	×	2	—	12	1	8	3
Solt, Qp_4	64	6	—	5	×	11	2	10	1
Ordas, Qp_4	72	4	—	6	—	3	7	6	2

Notations. × = below 1 wt.%; k = rock material of the Danube sediment; Q = quaternary formations; Qh-Qp = holocenic, pleistocenic genesis; Qp_4 = upper pleistocenic genesis; Qp_2 = low pleistocenic genesis; Qp-f = older pleistocenic sediments; Pl_3 = upper plyocenic genesis

In the mineral composition of the stone material transported by drift motion, correspondingly to the ablation area and due to the accumulation of fine sedimentary clastic rock material, sometimes magmatic and sometimes metamorphic minerals can be detected.

Figure 9 shows the classification of heavy minerals according to their origin (magmatic, metamorphic, epigenetic) in the sand of the Kisalföld region and in the Danube section of the Hungarian central chain mountains as well as in its left-side tributaries. At further analysis of the main mineralic components (in the particle size region of sand of 0.1—0.2 mm) with respect to their frequency and density, sediment transported from metamorphic and magmatic areas can be identified (Fig. 10).

In the Kisalföld region of the Danube mainly metamorphic, in unsignificant amounts magmatic heavy minerals — in the middle part of the Figure metamorphic, but a higher amount of magmatic minerals (biotite, pyroxene) than in the former — whereas in the lower part magmatic minerals are predominant.

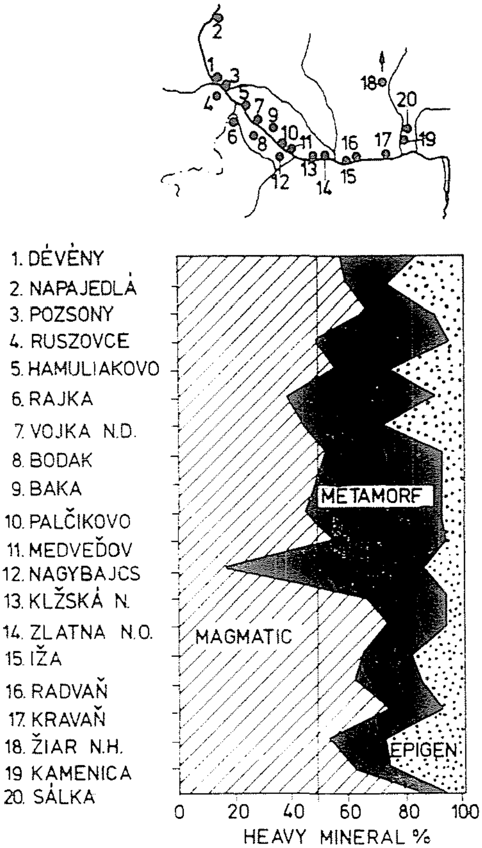


Fig. 9. Heavy mineral composition of the Danube and its left-side tributaries up to the Pilismarót region

Estimation of durability on the basis of changes due to freezing and crystallization processes

These studies are carried out if the material proved to be less durable by petrographic analyses.

a. *Study of the frost resistance of pebble and sand*

This procedure is one the oldest methods for studying model effects. Frost effect consists in the repeated cycles of freezing and thawing. The time of the effect is expressed as the number of regulated frost cycles. The frost resistance of a material originates from the durable resistance of the rock mass against chilling. The changes taking place in the material are recorded. Resistance is

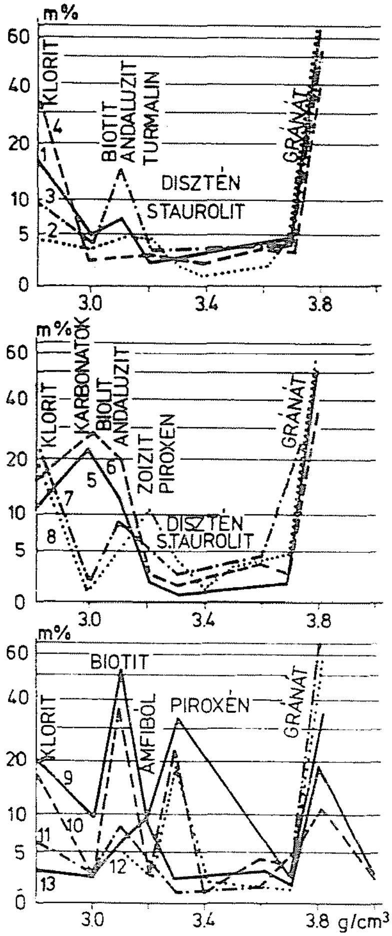


Fig. 10. Participation of heavy minerals by taking into account also their density.
Notations: 1 Dévény, 2 Napajedla, 3 Pozsony, 4 Rusovce, 5 Hamuliakovo, 6 Vajka n.D., 7 Bodak, 8 Baka, 9 Iza, 10 Radvan, 11 Kravány, 12 Kamenica, 13 Salka

derived from the continuous observation of the surface of rocks in the assembly, from changes taking place in them and from the number of freezing-thawing cycles not yet causing any change.

In order to determine changes in properties occurring as the result of short but strong stresses, the structural characteristics of rocks should be taken into consideration. Frost resistance is influenced by the extent, dimension, uniformity of fissures (fissures with uniform sections are less frost-sensitive than those with a variable diameter).

Not only the pressure of freezing water, but also the stresses caused by dimensional changes due to different temperatures inside the rock particles contribute to the effects.

Laboratory studies concerning frost effects differ from similar physical processes taking place in nature. In these studies we have to do without the long effect time of stresses. In nature, saturation with water and freezing of water in the fissures take place much slower. Thus what we measure is a change in properties occurring as a result of strong, but short acting stresses.

Refrigerator experiments were carried out according to a standard procedure.

The rock assembly was previously saturated with water, then placed into a cooling space (—20 °C) for 4 h, then into water (18 °C) for 2 h. Freezing loss was found to be (for particle sizes of 8—20 mm): wt% < 8 mm $= M_2/M_1 \times 100$
where wt.% < 8 mm is the freezing loss in weight percent
M_1 is the weight of rock before the experiment
M_2 is the weight of rock after the experiment.

In clastic sediments of naturally formed particle sizes very frost resistant quartz and quartzite, as well as differently frost sensitive rock types (magmatic, metamorphic and in part sedimentary) have been detected.

Frost breakage of the sediments in the *Danube region in the Kisalföld* (Fig. 11) lies below 2 wt.%, in the majority of cases it oscillates around 1 wt.%. The loss is largest for the rock material in Győr (older Pleistocene terrace pebble). The south-south-western layers of drillings are increasingly broken, but the loss does not exceed 2 wt.% even here.

In addition to quantitative analyses, the qualitative alterations on the surface of rock particles call the attention to the presence of less resistant rocks. Such are: the acidic magmatic rock, from among metamorphic rocks the epi- and mezometamorphic rock variants, the group of limestones with open, unfilled fissure networks. However, the participation of these rocks is small in the aggregate (Table 1). Quartzite rocks were resistant during the experiments. If they are broken, their hollow, corroded variants appear.

The experimental results for the coarse sediment in the *central chain mountain region of the Danube* show losses of about 1 wt.% except for the mantle rock of the Danube originating from the 1734 km section. The materials of Bőnyrét, Bana, Ács and Pilismarót are upper Pleistocenic, the other ones are the present drifts of the Danube.

The samples from the *Danube region in the Nagyalföld* (Fig. 13) show higher losses. Surprisingly high losses have been measured for the meso-Pleistocene terrace at Nagymaros and the lower Pleistocene material at Kiskúnlacháza Both materials contain different weathered andezite variants, andezite tuffs. The majority of metamorphic rocks in the samples from Kiskunlacháza is highly weathered (Table 1). Limestones and marls at the former place are also weakly resistant. The freezing losses of the materials from Verőcemaros, Vác, Dunakeszi, Káposztásmegyer, Pócsmegyer and Budakalász are larger by an order of magnitude than those of the present drifts shown in Figs 11 and 12 and

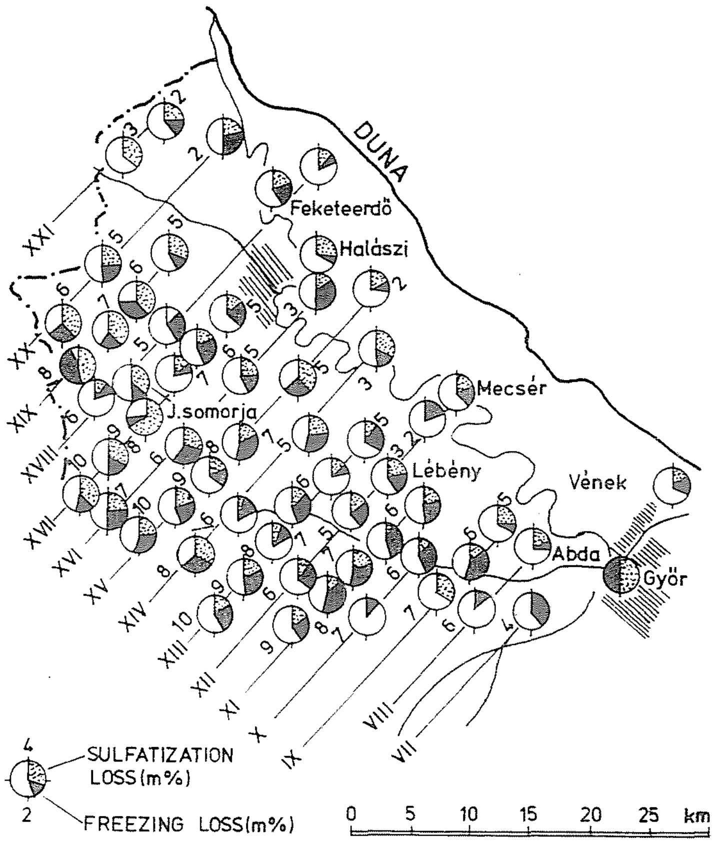


Fig. 11. Freezing losses of pebble sediments (8—20 mm), pebble mines, drillings in the Kisalföld region of the Danube

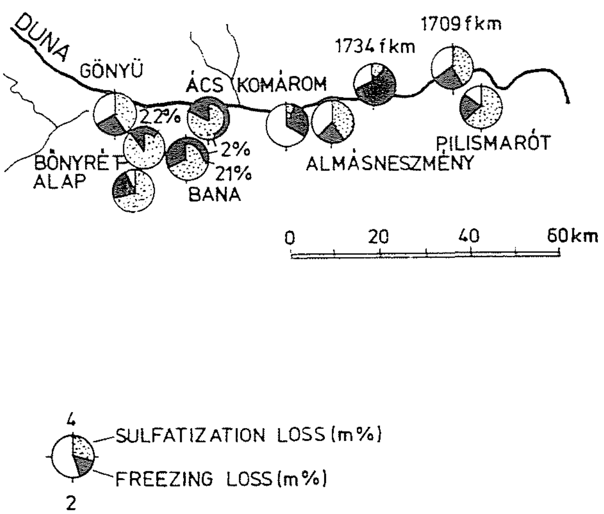


Fig. 12. Freezing losses of pebble sediments (8—20 mm), pebble mines and drillings in the central chain region of the Danube

those of upper Pleistocenic sediments (Fig. 13). The loss for the upper Pleistocene sample originating from the pebble fields south of Budapest is similar to that of the Kisalföld.

The sediments of Kisszentmihály (meso-pleistocenic Danube sediment) Cinkota, Vecsés (upper Plyocene) are essentially quartz, quartzite and quartzite slate. Their particle size corresponds to this origin.

In the Myocene sediments of Csomád and Törökbálint, weathered and non-resistant rock-types are present in a somewhat larger amount, thus their freezing loss is 4—6%. The material at Verőcemaros, Budapest-Árpád Bridge

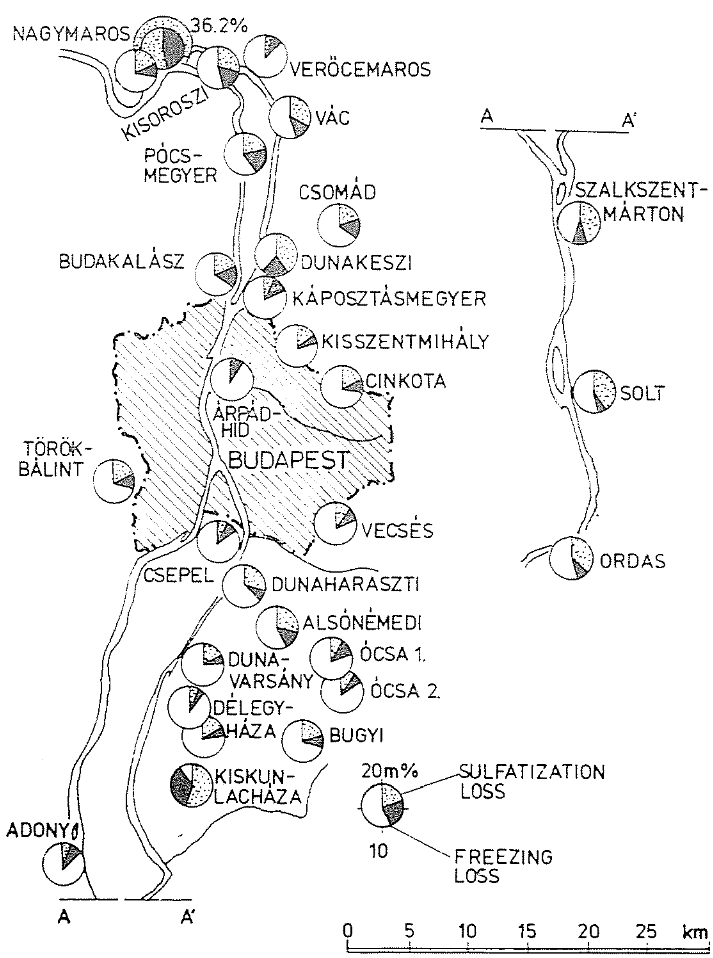


Fig. 13. Freezing losses of pebble sediments (8—20 mm), pebble mines and drillings in the Nagyalföld region of the Danube

and Adony is an aggregate group of the recent drifts of the Danube. Freezing losses at the central chain mountain section of the Danube are less than those found at the 1734 and 1709 km spots of Komárom.

b. *Crystallization experiments*

Crystallization experiments are model studies in which the frost effect is substituted by the crystallization stress arising when rocks are saturated with sulfate (sodium or magnesium) solutions. The sulfate solution exert a chemical effect as well. Due to the expansion of the sulfate crystal, the surface layer of the rock particle is loosened up or may even peels off in a thickness depending on the structure of the material and its porosity. The appropriate state of solutions, i.e. the density variations due to evaporation and temperature changes was carefully taken into consideration.

In physical dissolution, solubility changes with temperature. The over-saturated solution is in a labile state, and if crystallization starts in it owing to some internal or external effect, the amount of material in excess with respect to saturation, crystallizes.

According to experience, undesired density solutions arise during the preparation of solutions. When dissolving a salt, heat is abstracted, therefore it should be dissolved in higher temperature water. If we let the solution cool down slowly, large crystals precipitate, whereas a rapid cooling results in microcrystals which form a thin layer at the bottom of the vessel. In the latter case, the density required will change.

In our experiments, a gradual dissolution was carried out at a maximum temperature of 25 °C, then the solution was kept at the required temperature. The saturation of the solution was checked every time before use.

In the crystallization experiments the standard procedure was followed. Great care has been taken at sampling so that the sample would represent correctly the material of the settlement. Before experiments, the main rock components have been checked by so-called macroscopic methods.

Results for samples characterized by the mean values of losses obtained by using Na_2SO_4 and $MgSO_4$ solutions, together with the layouts of pebble mines and drillings are illustrated in Figs 11, 12 and 13.

In the *Kisalföld region of the Danube* the crystallization loss is 1—2 wt.%. In drillings in the south-western areas it is higher. The sediment studied is an upper-pleistocenic material. The loss in the sample from Győr is higher. (It is an older Pleistocene terrace pebble). Its freezing loss has been higher as well. A similar value was observed for the bore log XVII/8.

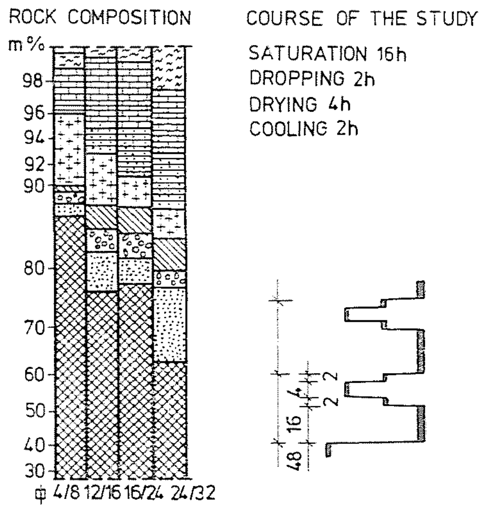
The sulfatization loss is caused by the weathering of magmatic, metamorphic and, to a smaller extent, sedimentary materials (weathered granite, quartz porphyry, arcose, phyllite, chlorite; slate, mica slate).

No damage occurred in the various quartzite rocks, certain limestones, quartzite slates. As resistant rocks, fine and coarse quartzites and sandstones can be mentioned.

The fragmentation of sediments from the *Danube section of the central chain mountains* (in the first line at Bőny, Bana and Ács) is higher than that in the Kisalföld region. The terrace pebble is of a weathered rock composition. Such are the drift samples at Komárom (1734—1709 km), the Holocene-Pleistocene pebble sediment at Pilismarót, Gönyű, Bőnyrétalap, Ács, Bana is upper pleistocenic Danube terrace pebble. The latter sediments contain significant amounts of metamorphic and sedimentary rocks, which are highly weathered, some are friable by hand (phyllite, marls).

The crystallization loss of the various sediments in the *Nagyalföld region of the Danube* is significantly higher than that of the above mentioned areas.

Upper-Pleistocene pebbles *north from Budapest* (Budakalász, Dunakeszi,



FRACTURING

φ	m%	2 4 6 8 10 12 14
24-32	12.0	
16-24	10.4	
12-16	9.7	
4- 8	8.3	

CYCLES STUDIED: 10

Fig. 14. Crystallization experiments with $MgSO_4$ solutions (Délegyháza). Notations are explained in the next Figure

Pócsmegyer, Vác, Kisoroszi) contain a series of rock variants of some mass percents, which show high crystallization fragmentation.

To the south of Budapest, both the older Pleistocene sediments (Kiskunlacháza, Bugyi, Délegyháza) and the upper pleistocenic stone material (Szalkszentmárton, Solt, Ordas) show high crystallization losses.

Weak, non-resistant andezite variants, andezite tuff pebbles originate from the Börzsöny and Pilis mountains. They play a significant part in the composition of sediments, e.g. the amount of andezite tuff in the pebble mine at Kiskúnlacháza is 5 wt.%, that of andezite is 10 wt.%. At Délegyháza, the ratio of andezite variants with different degrees of weathering is 8 wt.%, that of quartz porphyry is 1.6 wt.%. The amount of weathered metamorphic rocks is 6.5 wt.% at Délegyháza, and 2.5 wt.% at Kiskunlacháza.

Fragmentation losses: Kiskúnlacháza 11 wt.%, Szalkszentmárton 9 wt.%, Solt 7.4 wt.%, Bugyi 4.0 wt.%, Délegyháza 2.9 wt.%.

For the influence of the particle size and rock composition in crystallization losses the following conclusions may be drawn:

1. It can be established that for sharp particle size distributions the fracturing loss changes proportionally to the decrease in particle size (Fig. 14). Experiments were performed by using $MgSO_4$ solutions, the number of cycles was 10.

2. On considering the rock composition of Danube pebbles (Table 1) it can be stated that the major components are quartz and quartzite, though in different ratios. This is complemented by magmatic, sedimentary and metamorphic rocks in some tens of percents. The complex pattern for crystallization fracturing is shown in Fig. 15.

The number of cycles studied was 10, the particle size of the rock material was 4—6 mm diameters. Parallel studies were undertaken for particle sizes of 4—8 and 8—16 mm, by using the quartz-quartzite fraction only, and the entire material.

It can be established that if we assume the loss measured in the complete aggregate as 10 w%, and that of the 70 w% quartz and quartzite as 1.5 wt.%, then that of the part without quartz and quartzite has a crystallization loss, a weighted value of 29 wt%. Similar experiments were carried out also with $MgSO_4$ solutions. Identical trends were observed.

The results obtained by crystallization experiments, namely that the extent of fracturing is determined mainly by the amount of weathered material in the rock, are supported also by these investigations. The crystallization fracturing of the aggregate is rock-dependent.

3. Similarly, the role of rock quality is emphasized in the analysis of the crystallization of different quartzite rocks by using the two sulfate solutions.

Compact quartzite, coarse quartzite and porous quartzite of different origin have been evaluated. The maximum number of cycles was 10. The

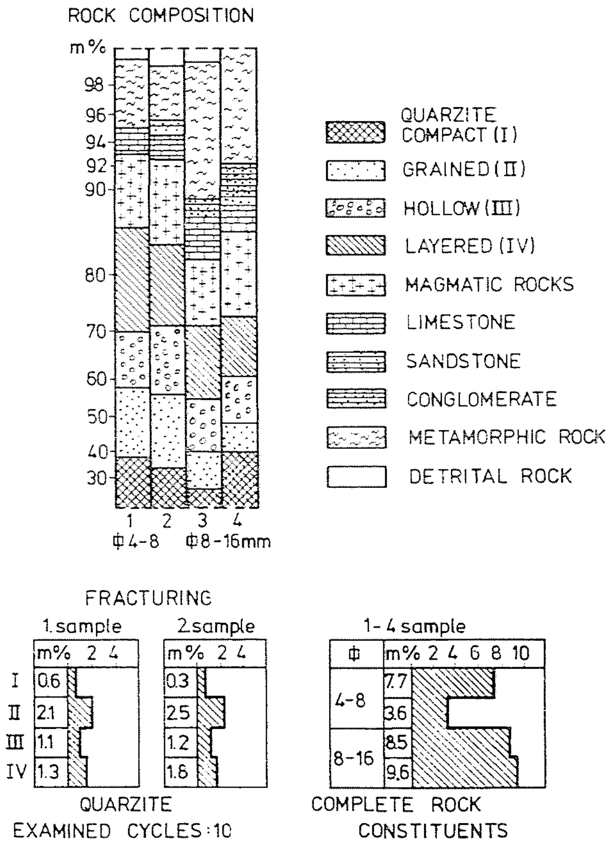
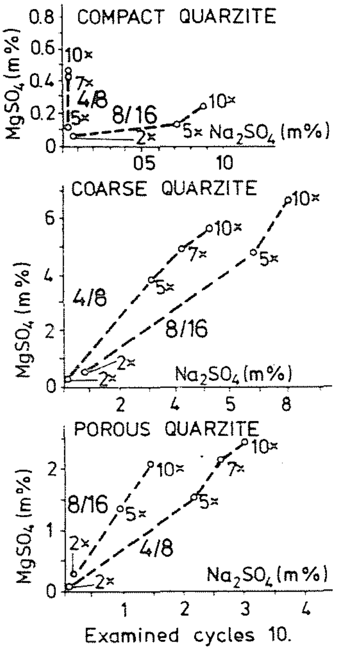


Fig. 15. Crystallization experiments with Na_2SO_4 solutions. Csepel

particle size of the aggregates studied was 4—8 and 8—16 mm in diameter. The breakage loss varies with the number of cycles, its trend is similar to that of the particle size.

Experiments were carried out under controlled conditions. Temperature and density were fixed and controlled continuously in using both different solutions and different particle sizes. The same conditions were ensured for the three different rock aggregates (Fig. 16).



Both of solutions:

DENSITY g/cm³		TEMPERATURE °C		
Na_2SO_4	$MgSO_4$	Na_2SO_4	$MgSO_4$	mm
1.160-1.167	1.299-1.305	20.9-21.1	20.2-21.2	4-8
1.160-1.168	1.298-1.305	20.2-21.1	20.2-21.0	8-16

1.161-1.167	1.299-1.305	20.4-21.0	20.7-21.2	4-8
1.162-1.165	1.298-1.305	20.1-21.0	20.6-21.2	8-16

1.161-1.166	1.298-1.305	20.4-21.0	20.6-21.2	4-8
1.161-1.167	1.298-1.305	20.4-21.0	20.6-21.1	8-16

Fig. 16. Crystallization losses at different cycle numbers and by using two different salt solutions

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